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Conservation of Seamount Ecosystems: Application of a Marine Protected Areas concept

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Abstract

Along with the growing body of knowledge of seamount ecosystems has come the realisation that the targeting of associated fish populations is currently unsustainable. For the most part, the target species are long-lived and slow to mature, with low fecundity. Benthic communities are also seriously damaged through disturbance by fishing gear and exotic species collection and could be impacted further in the future by exploitation of marine mineral resources. At current levels of knowledge concerning the structure and integration of seamount ecosystems, and in the light of experience with associated fisheries to date, sustainable exploitation cannot be envisaged. Accordingly, an holistic conservation strategy is required. This paper explores the elements of such a strategy based upon defining seamounts as fishery no-take zones and as areas protected from the full spectrum of human activities. Given the apparent individuality of seamount systems studied so far, this paper argues that a protective regime must be based on a large network of well-managed marine protected areas (MPAs), encompassing seamounts in all biogeographic zones, in order to conserve biodiversity effectively.

Kurzfassung

Schutz und Erhaltung von Seebergen: Das Marine-Protected-Areas-Konzept

Heutige wissenschaftliche Erkenntnisse zur Ökologie von Seebergen gehen davon aus, dass eine mit Seebergen assoziierte Fischerei nicht nachhaltig sein kann. Die meisten der befischten Zielarten sind langlebig und zeichnen sich durch niedrige Reproduktionsraten aus. Auch die benthischen Lebensgemeinschaften werden durch den Einsatz von Bodentrawls erheblich geschädigt. Im Rahmen derzeitiger Überlegungen zum Schutz von Seeberg-Lebensgemeinschaften (Marine-Protected-Areas-Konzept) (MPA-Konzept)müssen ganzheitliche Konzepte für ihren Schutz entwickelt werden. Ihre unterschiedlichen Ansätze und Strategien (z. B. Null-Nutzungszonen) werden vorgestellt. Ausgehend von der geographisch bedingten Diversität von Seebergen sollte ein über alle Zonen übergreifendes Schutzkonzept entwickelt werden.

Introduction

As noted by Roberts (2002), the world's deep oceans are also some of the world's last wilderness areas. Waters of over a kilometre in depth cover an estimated 62 % of the surface of the planet. Despite research efforts dating back to the HMS "Challenger" voyages of the early 1870's, it is only relatively recently that the complexities of deep sea systems have begun to be elucidated. At the same time, following the declines in shallow water fish stocks, the fishing

Arch. Fish. Mar. Res. 51(1–3), 2004, 305–319 0944-1921/2004/51/1–3-305

industry turned its attention to deep water environments. Developments in technology made such waters more accessible, and currently it is estimated that some 40 % of the world's trawling grounds now lie in waters deeper than those overlying the continental shelves. Koslow *et al.* (2000) state that, since 1964, deepwater fisheries have contributed between 0.8 and 1.0 million tonnes to landings of marine fish annually. This is a relatively small proportion of estimated global landings from marine capture fisheries, now standing at over 80 million tonnes per year (FAO 2002). However, the limited geographical extent from which this biomass is drawn coupled with the unusual life histories of the species commonly targeted over seamounts gives the potential for disproportionately large impacts.

Added to the disturbance potentially and actually attributable to fishing activities, deep water resources of minerals, oil, gas and gas hydrates are increasingly likely to be targeted in the future by the mining and the oil and gas industries respectively. Currently, much of the ongoing or planned commercial activity in deep water environments is taking place against a background of very poor knowledge of baseline ecological conditions. Hence, knowledge of the way in which these ecosystems are likely to respond to perturbation or subsequently to recover from anthropogenic impacts is virtually non-existent.

Within deepwater systems, seamounts are one of the most distinctive topographic features. Broadly, seamounts are defined as such when they rise at least 1000 metres above the sea floor, although the term is sometimes used to encompass a wider range of raised seabed features. Their formation is generally through volcanic activity, and often they occur as ridges or chains (Boehlert and Genin 1987; Wilson and Kaufmann 1987; Rogers 1994). Although the 1000 m classification is not universally applied, on this basis the Atlantic Ocean is estimated to contain 810 seamounts. The Pacific Ocean may contain upwards of 30 thousand such features. Research has focused in particular on those located in the waters around Hawaii, Australia and New Zealand. In common with hydrothermal vents and cold seeps, seamounts generally support diverse and productive assemblages of species, further challenging the previously held view that deep sea ecosytems are characteristically depauperate. Seamounts attract significant commercial interests as a result of the aggregation of exploitable populations of benthopelagic fish around them.

Seamounts as productive systems

Seamounts can cause substantial modification of flow patterns of the large ocean currents, although in most cases flow effects are more local (Boehlert and Genin 1987). Effects include the formation of eddies, trapping of waves and the amplification, distortion or reflection of internal waves (Rogers 1994). An upwelling of cold, deep water can appear as a dome over the seamount. Under certain conditions a clockwise eddy, known as a Taylor column can become localised above a seamount forming a closed circulation system. Precise circulation patterns appear to be specifically determined by individual seamount topography and location relative to currents, as illustrated by a study of seamounts off the coast of South America (Travassos *et al.* 1999).

Upwelling effects can cause appreciable increases in concentrations of phytoplankton nutrients as deep, nutrient-rich waters are brought close to the surface. Although some studies have recorded higher chlorophyll concentrations over or adjacent to seamounts, or even distinctive phytoplankton assemblages (Mouriño *et al.* 2001), these accumulations are often transient and a direct link with nutrient upwelling remains elusive (Comeau *et al.* 1995; Odate and Furuya 1998). Moreover, the extent to which the enhanced primary production transfers to higher trophic levels remains unclear (Rogers 1994). At the same time, the advection and entrainment of biomass from other areas, especially of diurnally migrating zooplankton, may be as, if not more, important in supporting a higher density of fish than in surrounding waters. It is likely that different components of seamount-associated food webs are impacted by the physical presence of the formation via different mechanisms (Dower and Mackas 1996). These aspects require further research to fully characterise and comprehend them. Nonetheless, what does seem clear is that the enhanced productivity associated with seamounts is reflected at all trophic levels, including an abundant and diverse benthic fauna dominated by suspension feeders and the highly aggregated fish populations found in their vicinity (Rogers 1994; Koslow *et al.* 2000).

Diversity of benthic communities

Wilson and Kaufmann (1987) concluded that seamount community structures were commonly similar to those found on nearby continental shelves. The fauna, however, is often dominated by suspension feeders, including various coralline species, due to the intensification of currents locally (de Forges *et al.* 2000). Shallow seamounts tend to have a greater component of species with restricted biogeographical ranges in comparison to the deeper seamounts which harbour assemblages of more cosmopolitan species (*e. g.* Gillet and Dauvin 2000).

In terms of biodiversity, however, an important aspect is the degree of endemism of organisms found in these systems. An early biogeographic study of 92 seamounts suggested that some 15 % of the species collected were endemic to individual seamounts (Wilson and Kaufmann 1987). This early work has been superceded by a more exhaustive study of seamounts in the Southwest Pacific which indicated that levels of endemism (*i. e.* the number of species previously undiscovered) among 850 macro- and megafaunal species could be as high 29 to 34 % (de Forges *et al.* 2000). These results support the premise that seamounts can function ecologically as island groups or chains, leading to localized species distributions and with apparent speciation between such groups and/or chains.

However, despite some 30 years of studies directed at seamounts, the knowledge base remains poor. In interpreting the data which are available, it is important to remember that apparent endemism could be an artifact of incomplete knowledge of the full extent of species distributions. The gaps in knowledge of benthic biodiversity in particular need to be resolved.

Seamount fisheries

It has been known for some decades that fish are often more abundant over seamounts than in the surrounding ocean waters. Prior to the development of deep-sea fisheries, primarily by the former Soviet Union, the benthopelagic fish taxa found in seamount environments were virtually unknown as a marketable commodity (Koslow 1996). Nonetheless, the aggregation of these fish over these topographical features allowed them to be readily targeted, giving a high yield per unit effort and making them particularly vulnerable to overexploitation. Pelagic armorhead (P*seaudopentaceros wheeleri*) have been exploited over seamounts in the central North Pacific since the late 1960s. Orange roughy (*Hoplostethus atlanticus*) has been fished intensively over a variety of seamounts and marine plateaux since the early 1980's, where initial catches could exceed 60 tonnes from a 20 minute trawl (Roberts 2002).

Reproductive strategies of the seamount-associated fish (in common with other deep-water species) are at the far end of the K-selected spectrum. They are exceptionally long lived, slow growing and slow to mature (Clark *et al.* 2000, Koslow *et al.* 2000). Orange roughy live to 150 years old, mature at 20 to 30 years of age and produce relatively few large eggs. Some *Sebastes* (rock-fish) species can reach an age of 200, while the Icelandic round-nose grenadier (*Coryphaenoides rupestris*) live well into their 70s, maturing at around 14 to 16 years old (Roberts 2002). In addition, recruitment of some commonly exploited species appears to be sporadic, depending in some cases on long-lived larvae originating remotely from the seamount (Koslow *et al.* 2000).

Vulnerability of seamount ecosystems

Fishing activities

The development of seamount fisheries has taken place against a background of relative ignorance of biological and ecological parameters. Both the highly K-selected life histories of these exploited species, coupled with sporadic recruitment to the stocks, have significant implications in relation to conservation of species and management of stocks. Excessive fishing pressure led to the commercial extinction of pelagic armorhead stocks over the Pacific seamounts northwest of Hawaii in less the 20 years. Some commercial exploitation continues and the stocks have not yet recovered (Roberts 2002). Although the landings of orange roughy have been stable in recent years, these have only been sustained through the serial depletion of stocks between southeastern Australia and New Zealand (Clark 1999).

Typically, newly discovered stocks have been fished down within 5 to 10 years to 15 to 30 % of the initial biomass (Koslow *et al.* 2000). Evidence of catch and effort data show very strong declines in catch rates over time (Clark 1999). Studies of the fished populations in New Zealand have identified that male fish now show a reduced size at maturity, with some evidence of reduced genetic diversity, although the evidence for these latter changes is conflicting (Clark *et al.* 2000; Clark and Tracey 1994). Establishing these seamount fisheries on a sustainable basis would likely require a very substantial (and probably unenforceable) reduction in fishing effort, combined with a much improved and deeper understanding of the biology and ecology of these fish on which estimates of sustainable yield could be based. In short, the problems of establishing sustainable fisheries over seamounts are generally similar to, but more intense than, those identified by Pauly *et al.* (2002) in the context of shallow water fisheries.

In addition to the population level impacts identified in targeted seamount fish species, community and ecosystem-scale impacts may also be expected (Koslow *et al.* 2000). While evidence for shifts in community structure due to fishing activities is considered at best highly equivocal (Jennings and Kaiser 1998) this conclusion is based largely upon data from shelf fisheries. Few studies have focused to date on community-level impacts of seamount fisheries. The influence of the relatively longer time scales over which biological processes operate in the deep ocean is unknown, and the onset of fishery activity too recent to allow such changes to be identified. Moreover, understanding of interactions between pelagic and benthic components of seamount systems remains in its infancy (Koslow *et al.* 2000).

Some of the clearest impacts on non-target species have been on benthic organisms. Because of the intensification and modification of water flow patterns around seamounts, the associated fauna tends to be dominated by suspension feeders, including various coral types (Wilson and Kaufmann 1987). Some impacts have taken place as a direct result of harvesting these corals (see below), though more extensive damage results from fishing activity, primarily trawling. One study of Tasmanian seamounts showed that benthic biomass per dredged sample was reduced by 83 % and species number per sample reduced by 59 % in a comparison of fished with un-fished areas. Bare rock characterised 95 % of the bottom substratum on trawled areas as opposed to 10 % on the most comparable, un-impacted area surveyed (Koslow *et al.* 2000; Koslow *et al.* 2001). The high degree of endemism of the fauna associated with these habitats renders the possibility of extinctions extremely high (Roberts 2002).

Other activities

In addition to the impacts of fishing activities on seamount ecosystems which affect both fish populations and benthic communities, other activities have the potential to impact upon seamount ecosystems. These include mining of resources from the deep ocean and the disposal of wastes (in particular fossil fuel-derived CO_2) into deep oceanic waters and directly onto the seabed.

Seabed mining

The exploitation of deep water fisheries associated with seamounts can be likened to "biological mining". In addition to this, deepwater corals have also been targeted as a resource for the jewellery trade (Koslow *et al.* 2001). Landings of deep-water coral currently stand at around 100 $t \cdot a^{-1}$, compared to a total global market for harvested coral of approximately 1000 $t \cdot a^{-1}$ (having declined from a peak of 4000 $t \cdot a^{-1}$ during the 1990s, Harriott 2003). Although these marketed tonnages are relatively low, the tangle netting method used in deep water is inefficient and can cause widespread collateral damage. Some of the species exploited or otherwise impacted are long-lived and suffer low natural mortality rates. Over-exploitation has led, in some regions (*e. g.* those areas harvested intensively by Japan and Taiwan in the 1980s) to rapid depletion of accessible coral populations to levels which were not commercially viable within only 7 years (Koslow *et al.* 2000).

In addition to the biological resources, a number of proposals have been made to recover mineral resources from the oceans through mining of the seabed (*e. g.* ISA 2002) and while no commercial recovery has taken place to date, these options are under active consideration. Regulation of such activities falls under the aegis of the International Seabed Authority . This body has been in full operation since 1996 and its tasks were defined by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) as refined by the 1994

Agreement relating to the implementation of Part XI of the Convention. The Authority has responsibility to organise and control all activities on or beneath the seabed of the global commons beyond the limits of national jurisdiction. Its Legal and Technical Committee acts to review applications from both public and private corporations and other entities, for exploration and ultimately exploitation of specified deep seabed areas for mineral resources (see http://www.isa.org.jm for information on the authority). It also has the mandate to recommend to the Council of the Authority measures regarding environmental protection and compliance monitoring. To date, the principle substantive result in this field has been the adoption in 2000 of regulations governing exploration for polymetallic nodules. Work has now begun on formulating regulations concerning exploitation of minerals associated with volcanic vents on the ocean floor, a task projected to take some years.

So far, little discussion has taken place on potential impacts of deep-sea mining activities on seamount ecosystems. This is despite the fact that mineral forms likely to be targeted are the ferromanganese crusts which occur largely on seamounts and other areas with unconsolidated sediments (Hein *et al.* 2000; see also: Figure 1 and http://www.isa.org.jm/en/seabedarea/TechBrochures/cobalt/Slide3.PNG).

All forms of seabed mineral mining are likely to be accompanied by significant near and far-field (several km from the mining operation) impacts, some of which are an unavoidable consequence of such operations (see *e. g.* Thiel 2001, for a review of potential impacts in the German claim within the Pacific region). Impacts on benthic fauna will result directly from the operation of machinery used for mineral recovery and may result indirectly from the resuspension of sediments. As Thiel (2001) notes, however, limited understanding of deep sea benthic ecology and genetics in the prospective regions greatly limit our ability to predict the precise nature and scale of impacts which will result from commercial scale mining operations. The same is true also in relation to possible impacts

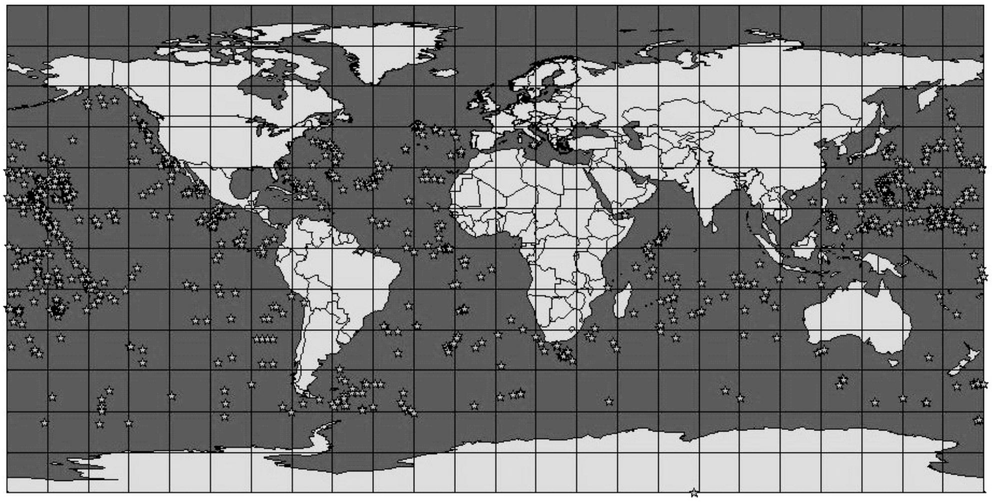

Figure 1: Cobalt-bearing ferromanganese crust sites sampled to date (adapted from the International Seabed Authority's Central Data Repository.

on the pelagic community down-current from mining activities and discharges (Koslow 2002). It is clear that in the immediate zone of operation, a very high mortality of organisms can be anticipated, especially of those which depend on mineral nodules for attachment. Further afield, modelling studies have indicated that resettlement of suspended materials (arising either directly from the seafloor or from discharge of waters following separation of nodules on a surface vessel) could take place several kilometres from the site of operations (Jankowski and Zielke 2001; Rolinski *et al.* 2001), though the biological significance of this is not known.

Further proposals have also been made to exploit methane gas hydrates, found in some deep water sediments, as an energy source (USGS 1992; Ginsburg 1998; Booth *et al.* 1994). The stability of sediments in these areas appears to be closely related to the presence and stability of the hydrates themselves, such that exploration and exploitation of these reserves could have large-scale and unpredictable impacts on sediment mobility. Once again, the potential for associated localised seafloor collapse (Booth *et al.* 1998) and sediment resuspension to impact upon deep-sea ecosystems, including seamounts, remains unknown. Nevertheless, given the growing interest in exploitation of such reserves, this is an additional activity of which the ISA needs to remain acutely aware.

Disposal of carbon dioxide (CO_2)

Recently, proposals to mitigate the impacts of anthropogenically driven climate change by capturing fossil fuel carbon dioxide and disposing of it into the deep ocean or into deep geological formations have provoked considerable and increasing debate, as exemplified by a workshop held under the auspices of the Intergovernmental Panel on Climate Change (*e. g.* Johnston and Santillo 2002). Proposals involving the ocean fall into two broad categories:

- Capture of carbon dioxide followed by disposal of liquid into intermediate depth ocean waters.
- Capture of carbon dioxide and formation of a lake of liquid carbon-dioxide (CO_2-clathrate bounded) on the sea floor.

Under the terms of current international law as enshrined in the London Convention (1972) and the 1996 Protocol to the Convention, both such activities appear to be illegal. As noted by Johnston *et al.* (1999) and Johnston and Santillo (2002), while the general engineering principles behind these schemata have been widely discussed, potential ecological impacts have received somewhat less attention and remain poorly described (Seibel and Walsh 2003; Tyler 2003). The predictions of these are largely predicated upon the extrapolation of known responses to pH reduction in shallow water organisms (see *e. g.* IEA 1996). Some observations have been made of the responses of deep-sea fish to extremely small quantities of CO_2 emplaced on the seabed (Tamburri *et al.* 2000). While these experiments have helped to elucidate the physico-chemical behavior of liquid CO_2 in deep marine systems on a small scale, they have not, of course, served to provide the basis to predict wider ecosystem effect.

The disposal of CO_2 into deep oceanic waters is likely to have qualitatively different impacts as compared to disposal into intermediate depth waters. The disposal scenarios have been described in a number of documents (Johnston *et al.* 1999; Herzog 2001). Broadly, it is anticipated that CO_2 dumped into deep marine waters will form a "lake" of liquid on the seafloor bounded by hydrates which will inhibit (though not prevent) its dissolution into the overlying water. By contrast, disposal into intermediate depth waters is assumed to result in a CO_2 enriched plume where diminished pH values are likely to persist for many tens of kilometers down-current, depending upon the degree of constraint imposed by *e. g.* density discontinuities through the water column. For either of these suggested disposal routes to be effective in mitigating anthropogenic climate change, they would have to be conducted on a very large scale, with multiple disposal sites operating in all ocean basins and conducted over a very long time scale of several decades. While it can be argued that such proposals merely accelerate the natural absorption of CO_2 by the oceans, there is clearly a very substantial difference between natural absorption taking place over the entire sea surface and forced absorption through artificial injection in deep water at multiple sites (Tyler 2003).

Whichever method of CO_2 disposal is used, it will ultimately dissolve and be dispersed with prevailing ocean currents. If disposal was conducted in deep or intermediate depth waters in the vicinity of a seamount, the resulting plume of low pH seawater could impact upon associated fauna. Organisms which build calcareous shells or skeletal structures such as bivalves or scleractinian corals could show suppressed growth (Kleypas *et al.* 1999), while a variety of negative physiological responses could result in other organisms (Seibel and Walsh 2001). Even if not immediately dispersed, CO_2 disposed of as a lake on the sea floor would act as a point source for a considerable period of time. Again, limits to existing knowledge on the structure and function of deep-sea ecosystems, and even on the biology of many species colonizing seamounts, renders even a qualitative prediction of impacts extremely difficult and uncertain. Nevertheless, the possibility of large-scale, possibly irreversible, adverse effects cannot be discounted. Future consideration of impacts likely to arise from deep sea CO_2 disposal must take full account of the diversity and limits to resilience of seamount ecosystems.

To date no such evaluation has been carried out. Description of the effect of these topographical features upon circulation patterns on a regional or local basis requires circulation models with a greater resolution than have been in common use, although recent advances in modelling and monitoring may ultimately make this more feasible (*e. g.* Lin and Chubb 2003). Seamount-induced changes in ocean circulation patterns could also have implications for the longer-term effectiveness of the proposed schemata as climate change mitigation options. If CO_2 enriched waters were to be brought to the surface as a result of circulation patterns, return of CO_2 to the atmosphere would be facilitated on a much shorter time frame than those predicted (and relied upon for effective sequestration) from the relatively coarse resolution ocean circulation models employed for this purpose to date (see Caldeira 2003 for a discussion on prediction of long-term fate of injected CO_2).

It is important to note that current proposals for ocean disposal of CO_2 carry serious legal implications in addition to their potential for ecological impacts. The London Convention of 1972 (formerly the London Dumping Convention) currently confers some protection against the dumping of wastes at sea. On the basis of amendments to the Convention agreed in 1993 (and in force since 1996), the disposal of industrial waste from vessels, aircraft or man-made structures at sea has been prohibited. Fossil-fuel derived CO_2 is not excluded from this definition.

Discussion: Conservation options

Concerns about the vulnerability of seamount ecosystems have led to widespread discussion of conservation strategies. It is widely recognised that fishing activity directed at seamount associated stocks is currently being conducted in an unsustainable manner, while the benthic habitats associated with seamounts can sustain considerable collateral damage. Added to these current impacts are the impacts which could result from *inter alia* the mining of minerals from seamount environments (possible in the long term) and the disposal of fossil fuel-derived carbon dioxide into intermediate and deep waters (possible in the medium term). If the risks of species loss or widespread habitat degradation are to be avoided, then a universally agreed conservation framework needs to be emplaced. This is likely to be a complex undertaking given that it needs both to accommodate the provisions of UNCLOS and allow for exploitation of seabed resources under the control of the International Seabed Authority. The potential for conflict between the needs for protection of biodiversity, including specific species and habitats, and the exploitation of mineral resources associated with seamounts is very real.

Irrespective of the complexities involved in devising a universally protective framework, one potentially highly useful strategy is the use of the concept of Marine Reserves/ Marine Protected Areas (MPAs). MPAs have become a recognised tool for marine conservation and marine resource management over the past decade. Nonetheless, many have been established without a clear view of the baseline conditions to be conserved, or how the designation will affect the areas (Halpern and Warner 2002).

For an MPA system to be effective it must incorporate a number of elements at both the conceptual and operational stages (see Box 1). Key to emplacing an MPA designation is a

Box 1: Guidelines for the development of marine reserves

- **Goals, objectives and expectations for the reserve must be specified, including the species, communities and habitats to be protected and, if appropriate, the role of the reserve within a network.**
- **Reserves should be selected to represent a broad spectrum of conditions, *i. e.* habitat types and qualities, communities, oceanographic features (including current systems, upwelling zones and retentive features), depth and latitude within biogeographic regions and levels of historic and/or ongoing human impact.**
- **Reserves should be designated according to appropriate scales of ecological and oceanographic processes, *i. e.* they must be large enough to be self-sustaining and to minimise edge effects.**
- **Placement of reserves within networks should consider dispersal and transport among sites within oceanographic features.**
- **As far as possible, reserves of similar habitat and community structure should be replicated, both to minimise the impacts of local catastrophic events occurring at any one site and to allow proper evaluation of reserve performance.**
- **Principles of adaptive management must be integral to reserve design such that changing conditions can be accommodated.**

(adapted from Fogarty *et al.* 2000)

clear understanding of the conservation objectives intended. Biological responses to protection, however, appear to develop quickly and to persist. Some 1300 MPAs have now been designated worldwide (Boersma and Parrish 1999) designed to provide refugia and also allow spillover of threatened species into waters exterior to the designated areas. To be effective as a conservation device, MPAs need to be both large and networked, and be representative of all biogeographic zones. (Parrish 1999; Mangel 2000). Indeed some negative fishery impacts may be exacerbated through the intensification of activities beyond the boundaries of an MPA. Even so, evidence exists that positive benefits accrue in some habitats such as coral reefs designated as MPAs (Jennings *et al.* 1996) and can allow depleted species to recover significantly (Kelly *et al.* 2000). Some of the key benefits, many of which could have direct relevance to seamounts, are summarised in Box 2. Some difficulties exist in applying MPAs to migratory species, but even with these, benefits can accrue (Guenette *et al.* 1998).

Relatively few MPAs have been designated to encompass seamounts. Fourteen are protected in this way in waters off Tasmania (Koslow *et al.* 2000), over an area of 370 square kilometres. New Zealand has protected 19 seamounts to some extent, and the US has designated an area encompassing two of these features off Alaska (Roberts 2002). In addition the US has designated Cordell Bank, a relatively shallow seamount, off the Californian Coast. Saba Marine Park in the Netherlands Antilles incorporates two offshore seamounts, while the Port Foster Site of Special Scientific Interest (SSSI) in Antarctica incorporates an undersea volcanic caldera.

The high degree of endemism associated with the fauna of seamounts surveyed to date implies that any conservation strategy based on MPA designation will require a network of reserves both within areas of national jurisdiction and on the high seas which are currently outside any regulatory scheme. Optimising the size and location of these reserves will inevitably require a deeper understanding of biogeography, ecology and reproductive strategy of the seamount associated fish and other fauna than we currently have. In the short term, however, there are some changes to current human activities which could already be

Box 2: Potential benefits of marine reserves

General

- **Increase habitat quality, protect or restore species diversity and community stability**
- **Provide undisturbed control sites for monitoring and assessing human impacts in other areas**
- **Create or enhance non-extractive, non-destructive uses, including tourism**
- **Reduce user conflicts**
- **Provide opportunities to improve public awareness, education and understanding**
- **Create areas with intrinsic value**

Fishery-related

- **Increase abundance, average size of target organisms, reproductive output and genetic diversity**
- **Enhance fishery yield in adjacent grounds**
- **Provide simple and effective management regime which is readily understood and enforced**
- **Guard against uncertainty and reduce probability of overfishing and fishery collapse**
- **Protect rare and valuable species**
- **Provide opportunities for increased understanding of exploited marine systems**
- **Provide basis for ecosystem management**

(adapted from Fogarty *et al.* 2000)

emplaced and which have a strong likelihood of success in terms of protection of seamount ecosystems. For example, changes in fishing practice, i.e moving from trawling to longlining would greatly reduce direct physical damage to the benthos and substrata (Koslow *et al.* 2000), though this could have implications for other species, including an increased threat of by-catch of seabirds (Bergin 1997; Tuck *et al.* 2001) and other predators, if not properly managed.

There are a number of aspects related to seamount ecosystem conservation which set them apart from systems normally protected through MPA designation and subsequent management. Notably, the level of baseline understanding of the systems is extremely poor, as evidenced by the high proportion of species new to science being described from these environments. Despite the generalised common properties of seamount systems, with respect to impacts upon circulation patterns and biological characteristics of the fauna, a high degree of specificity exists, reflected in part in the species endemism described from these systems. Hence an optimum strategy based on MPA designation will ultimately require seamount systems to be better characterised and the conservation objectives to be carefully defined.

It is clear that, with the current limited state of knowledge on seamount ecosystems, any management strategy which allows exploitation of living or non-living resources is associated with a high risk of failing fully to conserve biodiversity, even with respect to the simple objective of preventing species extinctions. Indeed, the substantial indeterminacies and uncertainties, coupled with the evidence of widespread over-fishing of seamount fisheries, suggest that a highly precautionary approach is merited.

In short, seamount protection is seemingly comprised of series of conundra which need to be resolved into effective management and conservation frameworks. Exploitation of living resources and the consequent direct and indirect impacts of fishing activities on seamount ecosystems are clearly the most immediate threats to which they are subject. The most effective way of conserving the biodiversity of these unique ecosystems from these particular threats would be to prohibit the targeting and marketing of benthopelagic fish over seamounts. This would also contribute very substantially to the conservation of the benthic species found in these habitats.

Further measures are likely to be necessary to protect seamount habitats if proposed seabed mining activities reach a commercial scale, particularly in the exploitation of ferromanganese crusts associated with seamounts. It is encouraging, at least, that the International Seabed Authority recognises seamounts as specific topographical features of the ocean floor environment and it must be hoped that the Authority will be able to exercise effective control in practice to minimise environmental impact of future commercial operations.

This oversight contrasts somewhat with the engineering-based approach which is still applied to most considerations of carbon dioxide disposal at sea. The prediction of long term behaviour of CO_2 disposed of in this way is based upon relatively coarsely resolved ocean circulation models. Indeed, modelling remains the only method of predicting such factors as retention time and dispersion pattern on a global scale. Seamount systems have not been incorporated into these models as yet and therefore their impact upon CO_2 return to atmosphere through turbulent mixing of deep waters with those closer to the surface has not so far been factored in. The modelling exercises conducted thus far consider the deep ocean largely as a system homogenous and isolated in both biological and physical terms.

Changing these misperceptions will be extremely important, even in the short term, if seamount systems are to benefit from effective conservation measures.

Conclusions

1. Seamounts are poorly characterised as regards location, numbers and associated ecological systems.
2. Seamounts support a rich and diverse benthic fauna with a high degree of endemism.
3. Seamount-associated fish are in general very long-lived species and hence extremely vulnerable to over-exploitation.
4. Some seamount fish and benthos are already known to have been seriously impacted by fishing activities.
5. Seamount systems have associated mineral resources in the form of ferromanganese crusts which could be the future target of seabed mining operations.
6. Gas hydrate mining could also take place close to seamount systems.
7. Seamount systems could be impacted substantially by disposal of carbon dioxide directly into deep ocean waters in their vicinity.
8. Conservation through designation of MPAs will require a mixture of national and supranational measures effective in law and realistically enforceable.
9. The simplest way of assuring adequate conservation in the face of the known properties of seamount ecosystems coupled with the associated uncertainties and indeterminacies is to cease all fishing activities targeting these populations.
10. Protection from mining activities will require early commitments to holistic conservation in practice by the International Seabed Authority.

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Received: 20 December 2002, accepted: 15 July 2003, print proof received from author: 24 August 2004.